AN OBJECTIVE COMPARISON OF PULSED, LOCK-IN, AND FREQUENCY MODULATED THERMAL WAVE IMAGING

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ABSTRACT. An objective comparison of three different thermal non-destructive evaluation (NDE) techniques – pulsed thermography (PT), lock-in (LI) thermography, and frequency modulated thermal wave imaging (FMTWI), has been carried out on a CFRP sample. The matched energy comparison shows that on the basis of computed SNR, the shallow defects are better detected by PT, while deeper defects are detected equally by all techniques.

Keywords: Pulsed Thermography, Lock-in Thermography, FMTWI, Matched Energy Comparison
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INTRODUCTION

Pulsed [1] and lock-in (LI) [2] thermography are the most commonly used thermographic nondestructive evaluation techniques. In pulsed thermography, the thermal images are recorded under pulsed heating of the test sample, often by an optical flash. By contrast, in LI, the thermal images are captured under periodic heating. The excitation frequency is chosen based on the diffusion length of the thermal signal. Since LI results suffer from blind frequency effect [3, 4], it is advised to repeat the experiments at multiple frequencies. The effort can be shortened by the application of frequency modulated thermal wave imaging (FMTWI), which is a superposition of multiple LI experiments [5, 6]. Fourier transformation is extensively used to generate phase and amplitude images from LI and FMTWI videos. Objective comparison of pulsed, LI, and FMTWI is not easy. A comparison based on computed signal-to-noise ratio (SNR) under matched energy condition has just been reported by the authors [4], and is summarized here.

EXPERIMENT

Figure 1a is a drawing of the test piece employed in all tests described in this paper. It is an approximately 7 mm thick carbon fiber composite board containing artificial defects. The test piece was painted with acetone soluble black acrylic paint to provide a greater surface absorptivity and emissivity. The 6 mm diameter defects only are considered for the comparison reported in this work.

Figure 1b shows the experimental setup for LI and FMTWI tests. For LI thermography, 16.7 mHz, 33.3 mHz, 50.0 mHz, 66.7 mHz, and 83.3 mHz frequencies were used, while

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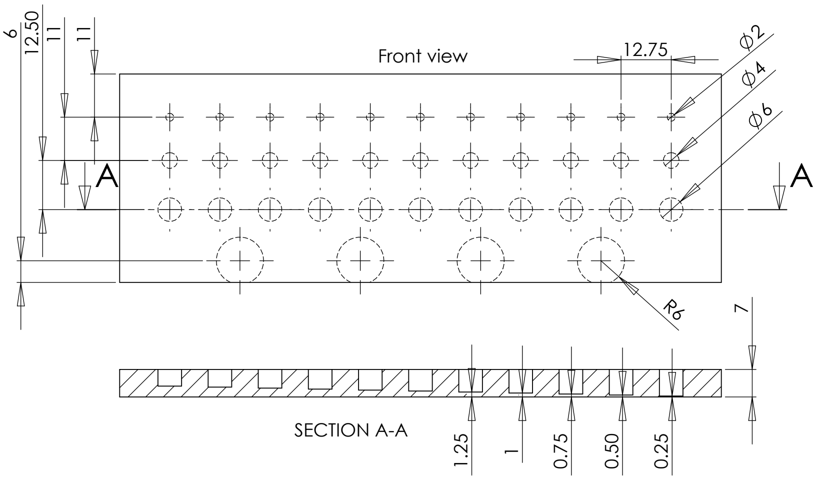
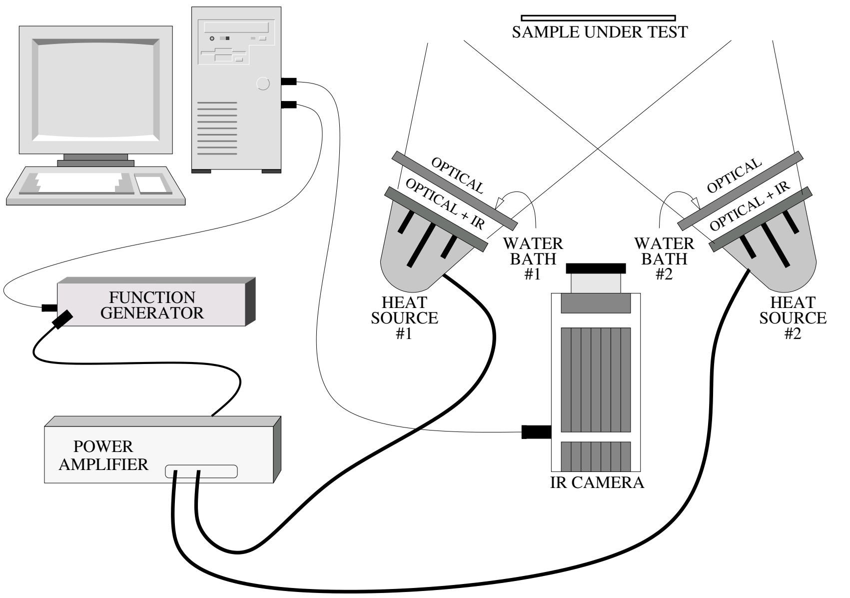


(a) CFRP sample (dimensions in mm).



(b) Experimental setup

FIGURE 1. Test piece and experimental setup.

a 20 mHz to 80 mHz up chirp was chosen for FMTWI. The heat source outputs were filtered for infra-red radiation with the help of water bath.

The comparison work was carried out under matched effective excitation energy condition. Since the energy level of the flash lamp used in pulsed experiment could not be varied, it was used as the reference. In LI and FMTWI, the flood lamps oscillation amplitude was so controlled that the effective absorbed AC energy was identical to that of the pulsed experiment. It is worth mentioning that the DC part of the heating in LI and FMTWI does not take part in the calculation of phase and amplitude images. Thus only the effective AC part was matched to the absorbed pulsed energy.

To achieve this, the pulsed experiment was performed first. The temperature vs. time data, which exhibits $1/\sqrt{t}$ behaviour on a sound region, was established. The absorbed energy was estimated from the frame after 1 second of the flash, as describe in the pulsed section of Table 1, and mathematically equated to the effective energy in LI thermography to calculate the amplitude of surface temperature oscillation under matched excitation energy

TABLE 1. Equations governing matched energy comparison for the three thermal NDE techniques.

Pulsed		
$T_P = E_P \big/ 2e\sqrt{\pi t}$	$E_P = T_P\Big\rvert_{t=1} 2e\sqrt{\pi}$	
T_P: Surface temperature, E_P: Absorbed energy, t: Time		
LI		
$T_{AC} = W_0/e\sqrt{\omega}$	$E_{LI} = 2W_0D/\pi$	$T_{AC} = \pi\, T_P\Big\rvert_{t=1} \Big/ D\sqrt{2f}$
f: Excitation frequency, $\omega = 2\pi f$, T_{AC}: Surface temperature oscillation amplitude, E_{LI}: Total effective absorbed energy in LI, W_0: Peak incident energy, D: Test duration		
FMTWI		
$E_{FM} = 37.9W_0$	$E_{LI} = 38.2W_0$	
E_{FM}: Total effective absorbed energy in FMTWI		

condition. The power of the heat sources were then set to achieve this oscillation amplitude. The LI section of Table 1 summarizes the method.

In FMTWI, the effective energy is almost identical to that of LI, as shown in the third section of Table 1. Hence the same power settings of the heat sources, as used in LI experiment, were repeated during FMTWI.

RESULTS

The comparison of pulsed, LI and FMTWI images is summarized in Fig. 2. It shows that for the shallowest defect, pulsed thermography produces the best signal-to-noise ratio, and LI and FMTWI magnitude images follow. It is interesting to note that the phase images produce the worst signal-to-noise ratio. For the deeper 1.25 mm defect, all techniques turn out to be equally good/bad.

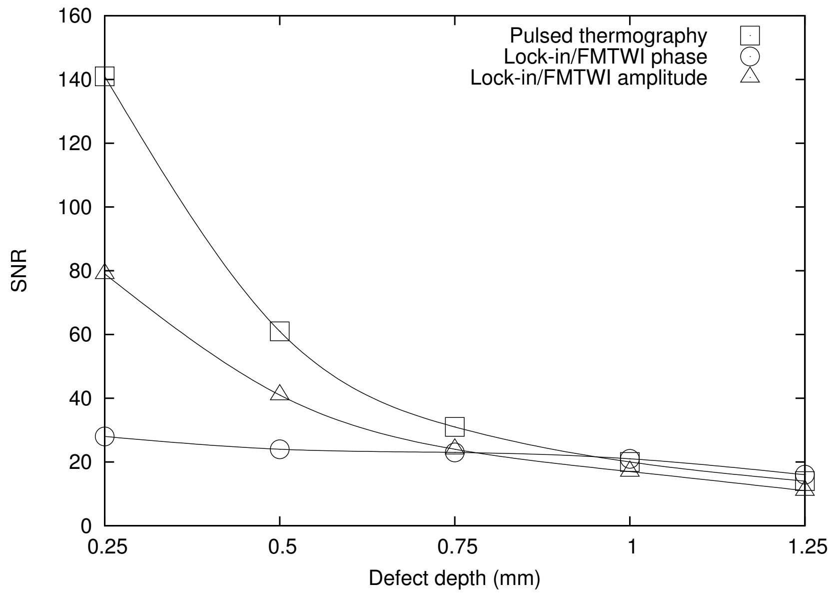


FIGURE 2. Plot of SNR as a function of defect depth.

CONCLUSION

In this paper, three thermographic techniques (*viz.* pulsed, LI and FMTWI) are compared based on effective excitation energy matching. It is shown that while for shallow defects the pulsed technique provides the best signal-to-noise ratio, its performance decreases for deeper defects. In the latter case, LI and FMTWI become comparable, if not better.

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